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USER'S GUIDE - COMPUTER PROGRAM - COMBUSTOR RELIABILITY PREDICT--ETC(U)
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AFAPL-TR-77-8
Volume III

USER'S GUIDE - COMPUTER PROGRAM - COMBUSTOR RELIABILITY PREDICTION

Vol II
B025 077L

UNITED TECHNOLOGIES CORPORATION
PRATT & WHITNEY AIRCRAFT GROUP, GOVERNMENT PRODUCTS DIVISION
WEST PALM BEACH, FLORIDA 33402

OCTOBER 1977

TECHNICAL REPORT AFAPL-TR-77-8, VOLUME III
Final Report for Period 15 June 1975 - 30 November 1976

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This technical report has been reviewed and is approved for publication.

Dale A. Hudson
Project Engineer

FOR THE COMMANDER

Ernest C. Simpson
Director, Turbine Engine Division
Air Force Aero Propulsion Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document has been written to serve as a guide to the user of the Combustor Reliability Production Program. This program relates burner crack initiation life and louver lip buckling life to the boundary conditions of compressor exit and turbine inlet temperature, expressed as a function of time. A description of the failure mode selection, model development and program sensitivity studies was included in the Final Report (Vol. I) under this contract.

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PREFACE

This final report was submitted by Pratt & Whitney Aircraft Group Government Products Division United Technologies Corporation, under Contract F33615-75-C-2057. The effort was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio with Dale Hudson/TBC as Project Engineer. Barry Schlein of Pratt & Whitney Aircraft was technically responsible for the work.

Technical assistance provided by W. H. Vogel and M. T. Loferski was essential to the completion of the project.

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SECTION I

INTRODUCTION

This document is a user's guide to the Combustor Reliability Prediction Program.

The program relates burner crack initiation life and louver lip buckling life to the boundary conditions of compressor exit and turbine inlet temperature, expressed as a function of time. The user must provide a set of reference conditions; metal temperature and strain range for a particular set of compressor exit and turbine inlet gas temperatures. The program then integrates the damage for each failure mode over the flight and provides a predicted life.

Section 2 of the document provides a program flow map, an engineering description, and a definition of the function of each subroutine. A detailed engineering description, including failure model selection, model development and program sensitivity studies, are provided in the final report for this Contract (Volume I).

Section 3 contains the input instructions, a listing of input for a sample case and the corresponding program output.

SECTION II

PROGRAM DESCRIPTION

1. General Description

The Combustor Reliability Computer program described in this report is a FORTRAN program compiled on both an IBM 370/168 at P&WA and a CDC 2000 for use at Wright-Patterson AFB. An overview of the program is provided in schematic form in Figure 1. The figure traces the flow of the calculation from the input stages through the calculation of component environment and incremental damage at each portion of the flight to the final summation of the damage for the mission. The appropriate subroutines are indicated by name in parenthesis in each box. Table I is a summary of the subroutine names and functions.

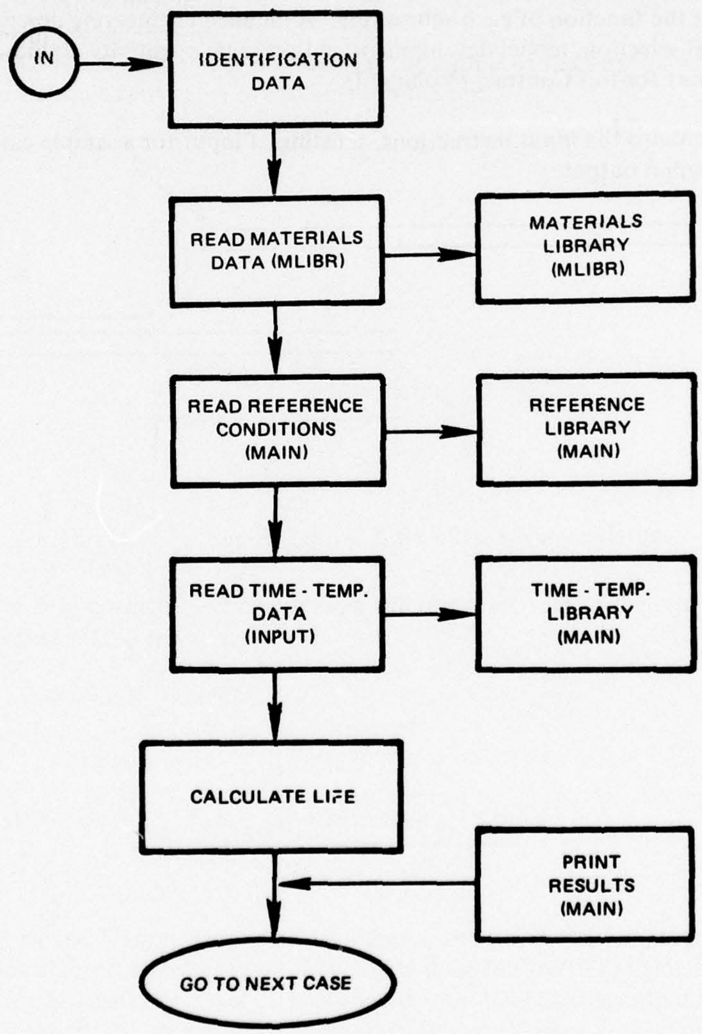


Figure 1. CRC Program Overview

TABLE 1

List Of Names, Routines, and Functions

Name	Type	Purpose
INPUT	Subroutine	reads in flight condition, temperature, and flight time
MAIN	Main Program	directs mission analysis program flow and calculates turbine metal temperature, stress, and strain range; reads in reference condition
MLIBR	Subroutine	reads and organizes materials' properties for turbine life analysis
UNBAR	Subroutine	interpolates two-dimensional tables

2. Life Calculation

a. Burner Creep-Low Cycle Fatigue (LCF) Cracking

This model, and the following one defining burner lip buckling life, are described in detail in the final report for this contract (Volume I).

The nomenclature for this section is described in Figure 2 and the following table.

A, B = Influence coefficients for temperature referencing

B_t = Time - temperature dependent plastic stress-strain relationship

C = Strain-temperature proportionality constant, a function of material and radius.

D_p = Material ductility

E = Youngs modulus

f = Flight increment

K_1 = Temperature dependent plastic strain relationship

L = Life

m = Total number of increments

n = Slope of the material LCF curve

N_c = Damage fraction associated with creep

N_f = Damage fraction associated with LCF

T_K = Louver knuckle temperature

T_M = Metal temperature
T_{MR} = Reference condition metal temperature
T_1 = Combustor inlet temperature
T_{1R} = Combustor inlet temperature under reference conditions
T_2 = Combustor exit temperature
T_{2R} = Combustor exit temperature under reference conditions
$\Delta\epsilon_C$ = Endurance limit strain range
$\Delta\epsilon_{TR}$ = Total strain range

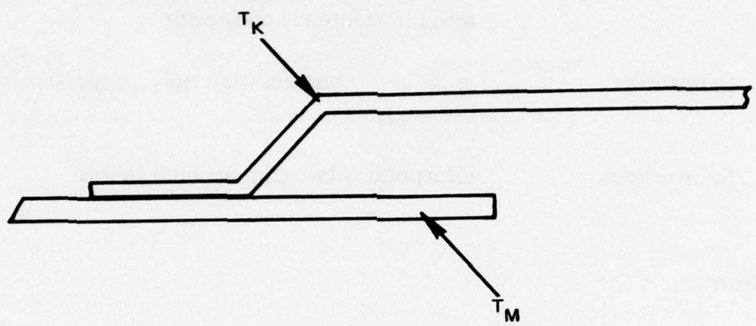


Figure 2. Burner Creep – LCF Nomenclature

At any flight condition, the metal temperature is related to temperatures at the reference conditions by:

$$T_M = T_{MR} + A(T_1 - T_{1R}) + B(T_2 - T_{2R}) \quad (1)$$

The cold knuckle of the louver (See Figure 2) is

$$T_K = T_1 + 20°F \quad (2)$$

and the total strain range is calculated from

$$\Delta\epsilon_{TR} = C\left[T_M - T_K\right] \quad (3)$$

The program has built in curves of C as a function of radius for bending and hoop stress. The user selects the failure mode (axial or circumferential cracking). A fatigue damage fraction is calculated for take-off conditions (equation 4) and a creep damage factor is calculated over the entire flight spectrum (equation (5).

$$N_f = \left(\frac{\Delta\epsilon_{TR} - \Delta\epsilon_e}{D_P} \right)^{1.667} \tag{4}$$

$$N_c = \left[\frac{(\Delta\epsilon_{TR})^{1/n}}{1.25\, D_P E} \right]^{1.25} \left\{ \left[K_1^{-1/n} - (B_{t_{i-1}})^{-1/n} \right] + \sum_{i=2}^{m} \left[B_{t_{i-1}}^{-1/n} - B_{t_i}^{-1/n} \right] \right\}^{1.25} \tag{5}$$

The values of $\Delta\epsilon_e$, D_P, E, K_1 and B_t are functions of temperature (Bt is a function of time as well) and are obtained by interpolation of input data tables. The cracking life is then:

$$L = \frac{f}{N_c + N_f} \tag{6}$$

b. Burner Louver Lip Buckling

The burner louver lip buckling model is a dual mechanism failure model of thermal buckling and coating induced buckling. Failure is considered to occur when the lip is completely closed. Temperatures for this failure model are the same as those used in the creep – LCF model described in the preceding section (equations 1 and 2). Nomenclature for this section is described in Figure 3 and in the table below:

b	=	Materials property parameter
C_{ri}	=	Hoop restraint factor
C_{ro}	=	Geometric hoop restraint factor
E	=	Youngs modulus
i	=	flight increment
k	=	Lip buckling coefficient
L	=	Lip length
m	=	Material property parameter

n	=	total number of flight increments
T_C	=	Critical buckling temperature
T_K	=	Louver knuckle temperature
T_M	=	Louver lip temperature
t	=	time
t_f	=	time to failure
W	=	Lip height
W_t	=	Thermal buckling
δ	=	Strip coating deflection
Δt	=	Time increment

The subscript MAX refers to the largest value over the course of the mission while the superscript* indicates an equivalent value as explained in the text.

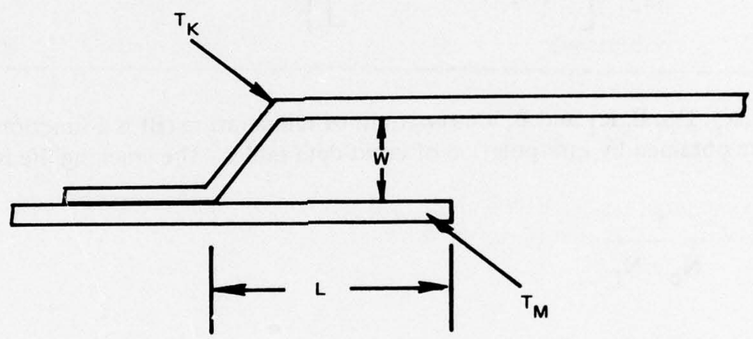


Figure 3. Burner Louver Lip Collapse Nomenclature

The temperature below which thermal buckling will not occur, called the critical buckling temperature, is determined from:

$$T_C = \Delta\epsilon_{ce}/k + T_K \tag{7}$$

where:

$$\Delta\,\epsilon_{ce} = \frac{\Delta\,\epsilon_{cp} E' + m \ln(\Delta\,\epsilon_{cp}) + b}{E + E'} \tag{8}$$

The values of E, m and b are functions of the material and hot metal temperature T_M while E′ is Youngs Modulus, evaluated at the cold knuckle temperature. The value of k is a function of the lip geometry and $\Delta\,\epsilon_{cp}$ is calculated from built in curves that relate the critical plastic strain to the lip temperature and buckling coefficient.

If the critical buckling temperature is exceeded, the lip buckles by an amount relative to the total strain. The curve, independent of material and radius, is built into the program. The program takes the maximum value of lip strain to calculate the thermal buckling.

Superimposed upon the thermal buckling is a coating induced buckling which forces the lip to close as a result of volumetric lip changes in the coating. The amount of closure is proportional to the geometry, temperature, and time at temperature. In any time increment, the amount of closure is:

$$W_{c_i} = C_{r_i} \left(\frac{L}{1.5} \right)^2 \delta_i \tag{9}$$

C_{ri} is a geometric restraint factor that varies from C_{ro} at or below the critical buckling temperature to 1 at 2000°F (1367°K). C_{ri} is a function of lip geometry and is a part of the program. The coating strip deflection δ_i is a function of time at temperature and is computed from curves that are also a part of the program.

Since the lip temperature varies with each flight increment, an equivalent term is calculated to reach the deflection just prior to the start of the increment and at the new temperature. If δ_{i-1} represents the coating strip deflection up to the flight increment and T_{M_i} the new lip temperature:

$$t^*_{i-1} = f \left[\delta_{i-1}, T_{M_i} \right] \tag{10}$$

$$\delta_i = f \left[t_{i-1}^* + \Delta t_i, T_{M_i} \right] - \delta_{i-1} \tag{11}$$

At the conclusion of the flight, an equivalent temperature is calculated such that

$$T^* = f \left[\sum_{i-1}^{n} \delta_i, \sum_{i-1}^{n} t_i \right] \tag{12}$$

Since failure is assumed to be the complete lip closure, the amount of strip coating closure for failure is

$$\delta_f = \frac{W - W_{t\,max}}{C_{r_{max}} \left(\frac{L}{1.5} \right)^2} \tag{13}$$

and the time to complete collapse

$$t_f = f \left[\delta_f, T^* \right] \tag{14}$$

SECTION III

PROGRAM OPERATION

This section describes both the input information and format required to run the mission analysis-failure model program, and the output from the program. A sample case (input and output) is also provided.

1. Program Input

a. Program Instructions

Details of the input for this deck, and the format of the input, are described in the following pages. Each page (or more than one page if required) illustrates and describes each data card or type of data card. Each card or type of card is divided into fields, or sequences of card columns, into which are entered the input parameter values.

Data will always be input in one of the three following forms:

- Floating point number (denoted by F. P.) – this form of input may consist of the characters "+", "–" 0-9, and "." (decimal point). If neither "+" nor "–" is input, then a positive number is assumed. The decimal point must be input unless otherwise specified. If the decimal point is input, then a number may be entered anywhere within its field. An additional character, "E", may be used to input a floating point number with an exponent. For instance, the number 13,460,000.0 may be input as .1346 E8 or the number 0.0000001346 may be input as .1346 E-6. When a number is input with an exponent, then the exponent (E-6 for example) must be right adjusted within its field.

- Integer number (denoted by INT.) – this form of input may consist of the same characters as a floating point number except for the decimal point (a decimal point must not be input). An integer number must be right-adjusted within its field.

- Alphanumeric input (denoted by A/N) – this form of input may consist of any character available on the computer and may be entered anywhere within its field.

If the input field for a floating point number or an integer number is left blank, then a zero is assumed. Blanks in alphanumeric input will be blank characters.

b. Input Package

The input package is divided into three parts, as described below:

- Part 1 consists of the first card indicating the number of cases to be run and the number of burner material packages to be input.

- Part 2 (card types 2-7) defines the material properties. Up to five packages can be loaded.

- Part 3 is the reference condition package including eight data cards.

  The case title card (card type 8) indicates the number of reference conditions, up to 5. The program will generate a life prediction for each reference condition input.
  Card type 9 describes the flight duration and frequency used for averaging damage over a mixed set of missions.
  Card type 10 identifies the material and the failure mode (cracking or buckling).
  Card type 11 indicates the number of reference modes (louvers) to be analyzed plus the units of temperature input.
  Card type 12 identifies the compressor exit and turbine inlet temperatures at the reference conditions.
  A card type 13 is required for each louver to be analyzed to define parameters for either the cracking or buckling failure model.
  Card type 14 identifies the flight condition and the time-gas temperature boundary condition.
  The last card of each case (type 15) contains a minus 1.

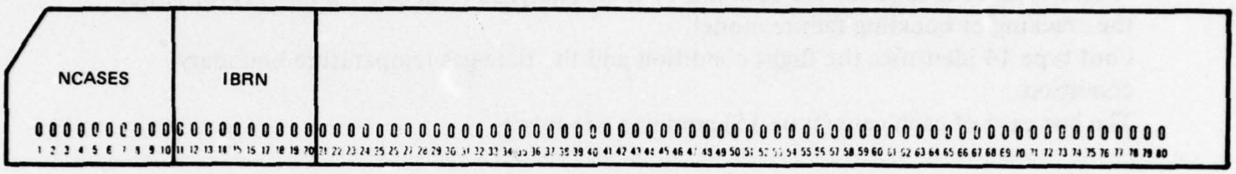
NOTE

The input data cards, as described above, are illustrated on pages 10-24 following.

Card Type: 1

Title: Indicator Card

General Instruction:



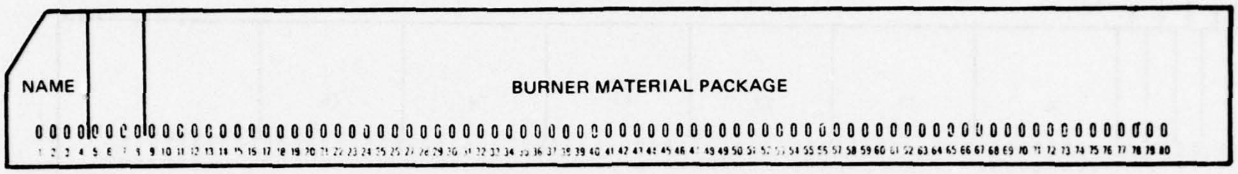
Name	Type	Column(s)	Description
NCASES	INT	1-10	Total number of cases to be run (no limit). Each case is described by cards 8-14.
IBRN	INT	11-20	Number of Burner Material Packages input, up to a maximum of 5. Input described by card types 2-7.

Card Type: 2

Title: Burner Material Package

General Instruction:

Input package IBRN times if IBRN >0 on card Type 1, Columns 11-20.

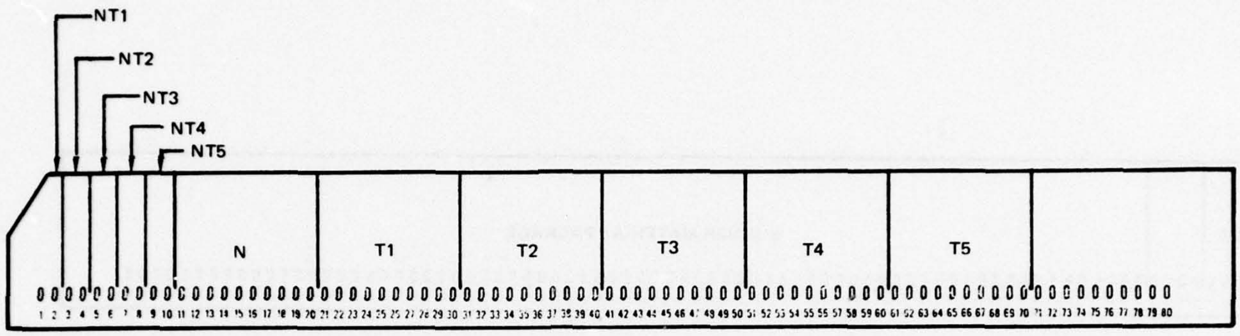


Name	Type	Column(s)	Description
NAME	INT	1-4	Material name (1038, 5566, etc.)
TITLE	A/N	9-80	Descriptive title of material package.

Card Type: 3

Title: Burner Material Package

General Instruction:



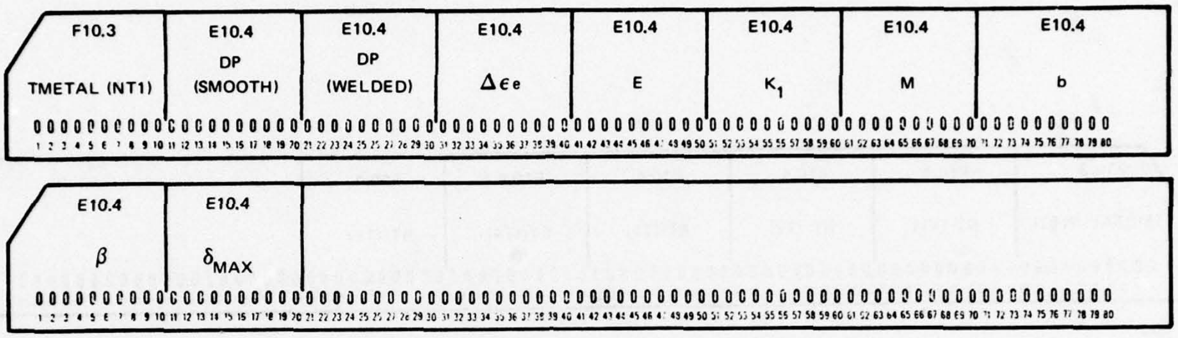
Name	Type	Column(s)	Description
NT1	INT.	1-2	Number of metal temperatures used to define parameters on card type 30 Max = 9
NT2	INT.	3-4	Number of metal temperatures used to define BT curve. Max = 9
NT3	INT.	5-6	Number of ϵ_{TR} and corresponding buckled deflection values input. Max = 15
NT4	INT.	7-8	NT + NT5 $\leq$ 20 — No. of Tm for ϵ_{CP} curve
NT5	INT.	9-10	No. of buckling coeff. for ϵ_{CP} curve
N	F.P.	11-20	Material constant (N = 2.35 for 1038)
T1	F.P.	21-30	
T2	F.P.	31-40	
T3	F.P.	41-50	Time input for BT curve (input in ascending order)
T4	F.P.	51-60	
T5	F.P.	61-70	

Card Type: 4 (Optional)

Title: Burner Material Package

General Instruction:

Repeat these 2 cards NT1 times.



Card	Name	Type	Column(s)	Description
	TMetal (NT1)	F.P.	1-10	Metal temperature at which the following 9 parameters are taken. (°F)
	DP (Smooth)	F.P.	11-20	BRN cracking parameter.
	DP (Welded)	F.P.	21-30	BRN cracking parameter.
	$\Delta\epsilon_e$	F.P.	31-40	BRN cracking parameter.
1	E	F.P.	41-50	BRN cracking + buckling parameter.
	K_1	F.P.	51-60	BRN cracking parameter.
	M	F.P.	61-70	Louver buckling parameter.
	b	F.P.	71-80	Louver buckling parameter.
	β	F.P.	1-10	Louver buckling parameter (log value)
2	δ_{Max}	F.P.	11-20	Louver buckling parameter.

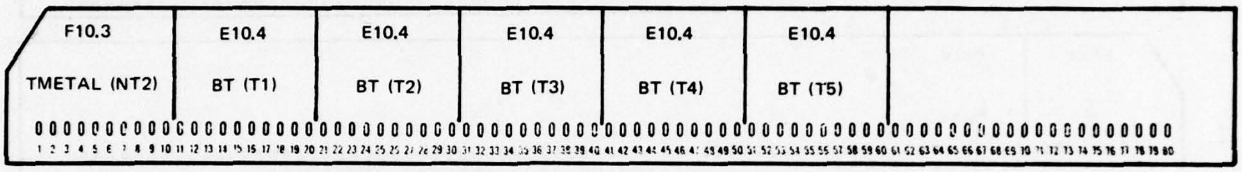
Taken from materials curves provided corresponding to TMetal (NT1)

Card Type: 5

Title: Burner Material Package

General Instruction:

Repeat this card NT2 times.



Name	Type	Column(s)	Description
TMetal (NT2)	F.P.	1-10	Metal temperature for the corresponding values of BT (Repeat card NT2 times) – °F
BT (T1)	F.P.	11-20	Time – temperature dependent parameters (Input to correspond to T1 → T5 and TMetal)
BT (T2)	F.P.	21-30	
BT (T3)	F.P.	31-40	
BT (T4)	F.P.	41-50	
BT (T5)	F.P.	51-60	

Card Type: 6

Title: Burner Material Package (Strain Range - Buckled Deflection)

General Instruction:

Input values continuously leaving no blank fields.

E10.4	E10.4	E10.4	E10.4	E10.4	E10.4	E10.4	E10.4
ϵ_{TR} (1)	ϵ_{TR} (2)		ϵ_{TR} (NT3)	WB (1)	WB (2)		WB (NT3)

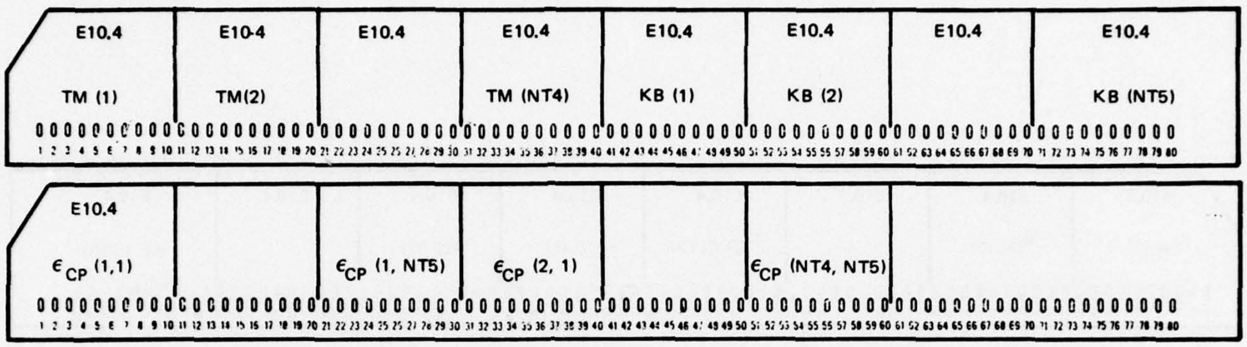
Name	Type	Column(s)	Description
ϵTR (1→NT3)	F.P.	1-As Required (In Fields of 10)	Total strain range.
WB (1→NT3)	F.P.	Fields of 10 Immediately Following ϵ_{TR} Values	Buckled deflection corresponding to ϵ_{TR} (NT3) values

Card Type: 7

Title: Burner Material Package (Critical Plastic Strain Curve)

General Instruction:

Input values continuously leaving no blank fields.

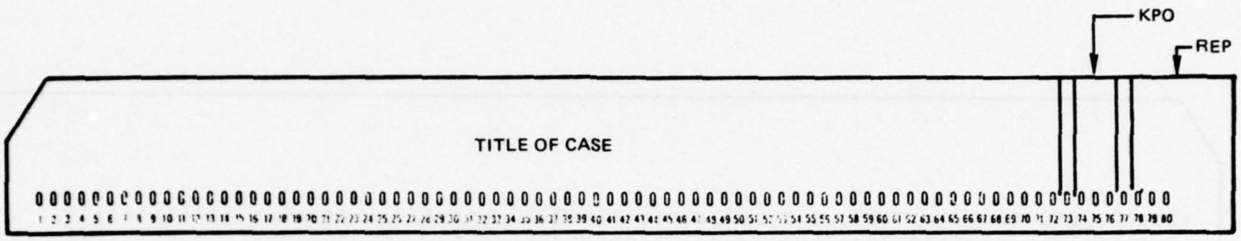


Name	Type	Column(s)	Description
TM (1 → NT4)	F.P.	1-80 As Required in Fields of 10	Metal temperature for critical plastic strain curve. – °F
KB (1→ NT5)	F.P.	1-80 As Required in Fields of (immediately following last TM value input)	Buckling coefficient for critical plastic strain curve.
ϵ_{CP}(1,1→NT4, NT5)	F.P.	1-80	Critical plastic strain [Input values of ϵ_{CP} continuously along lines of constant metal temp. (TM) for given buckling coefficients (KB).]

Card Type: 8 (Required)

Title: Case Information

General Instruction:

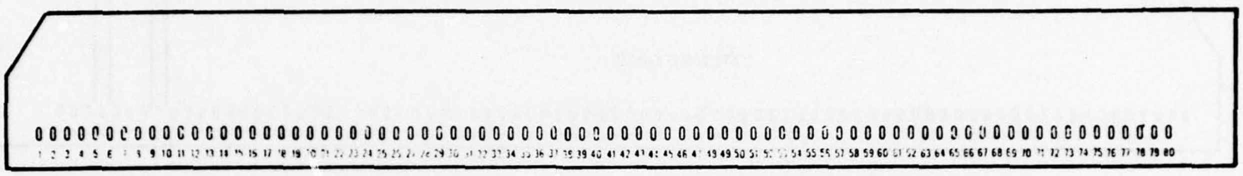


Name	Type	Column(s)	Description
TITLE	A/N	1-72	Descriptive title describing case.
KPO	INT	74-76	Printout Option 0 – Standard 1 – Expanded
KREF	INT	78-80	Number of reference conditions up to a maximum of 5.

Card Type: 9

Title: Case Information

General Instruction:

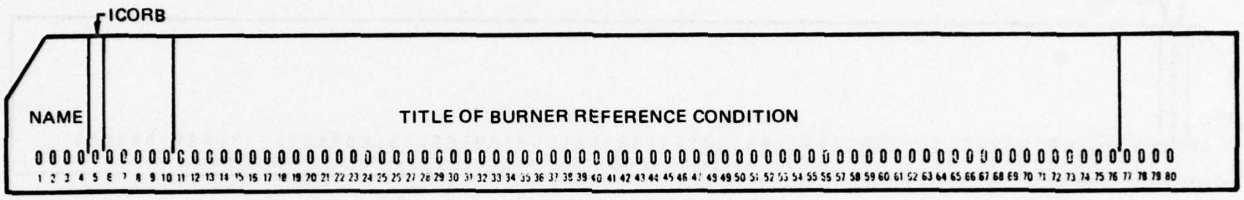


Name	Type	Column(s)	Description
BT	F.P.	1-10	Block time - hours.
TT	F.P.	11-20	Taxi time - minutes.
FREQ	F.P.	21-30	Frequency of flights. When more than one case is run; the program will weight the damage for each case and print a summary life based upon each case and its frequency.

Card Type: 10

Title: Burner Cracking or Buckling Reference Condition

General Instruction:

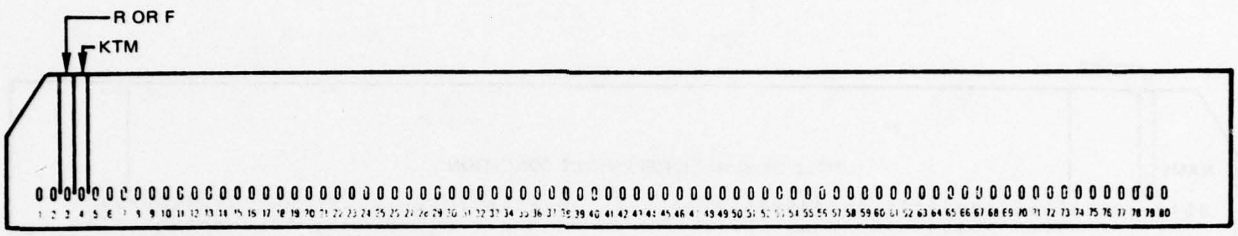


Name	Type	Column(s)	Description
Name	INT.	1-4	Material name (1038, 5536, etc.)
ICORB	INT.	5	Indicator for cracking or buckling model (1 = cracking, 2 = buckling)
Title	A/N	11-76	Descriptive title or burner reference condition

Card Type: 11

Title: Burner Reference Condition

General Instruction:

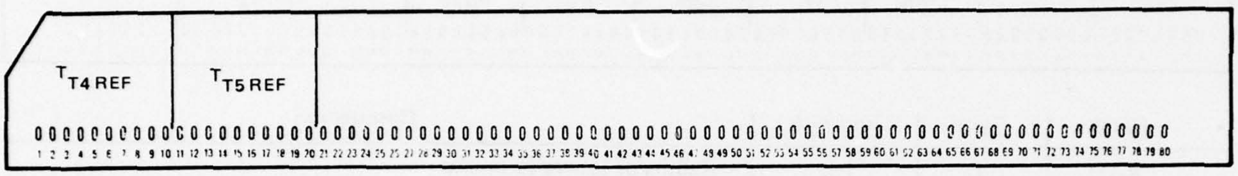


Name	Type	Column(s)	Description
NR	INT	1-2	Number of louvers, up to a maximum of 9, examined
RORF	INT	3	°R or °F (0 = °R, 1 = °F)
KTM	INT	4	= 1 for burner

Card Type: 12

Title: Burner Reference Condition

General Instruction:



Name	Type	Column(s)	Description
TT4 Ref	F.P.	1-10	Reference T_{T4} (°R or °F)
TT5 Ref	F.P.	11-20	Reference T_{T5} (°R or °F)

Card Type: 13

Title: Burner Reference Condition

General Instruction:

Repeat NR Times

F8.5	F8.5	F8.5	F8.5	F8.5	F8.5	F8.5	F8.2	F8.2	F8.2
RAD	L	L^2/RH	W	CHB	A_{REF}	B_{REF}	BTMR	T_4(FI)	T_5 (FI)
1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72	73-80

Name	Type	Column(s)	Description
RAD	F.P.	1-8	Radius of louver in inches
L	F.P.	9-16	Louver lip length in inches – (not input if ICORB = 1)
L2/RH	F.P.	17-24	Non-dimensional constant – (not input if ICORB = 1)
W	F.P.	25-32	Non-deflected louver lip gap (See Fig. below)
CHB	F.P.	33-40	Hoop or bending stress 1. = bending stress outer liner 2. = hoop stress - outer liner 3. = hoop stress - inner liner
AREF	F.P.	41-48	Influence coefficient for T_4
BREF	F.P.	49-56	Influence coefficient for T_5
BTMR	F.P.	57-64	Reference Metal Temperature
T4(FI)	F.P.	65-72	Flight idle T_4
T5(FI)	F.P.	73-80	Flight idle T_5

$$T_M = A_{REF}(T_4 - T_{4\,REF}) + B_{REF}(T_5 - T_{5\,REF}) + B_{TMR}$$

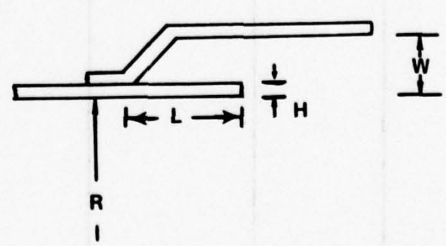


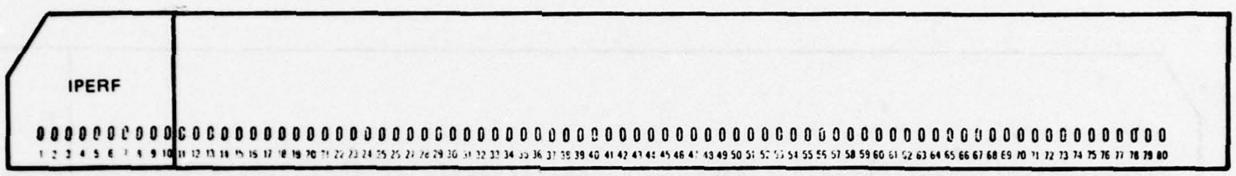
Figure 4 Louver Geometry

Card Type: 14

Title: Time - Temperature Boundary Conditions

General Instruction:

As many as required.



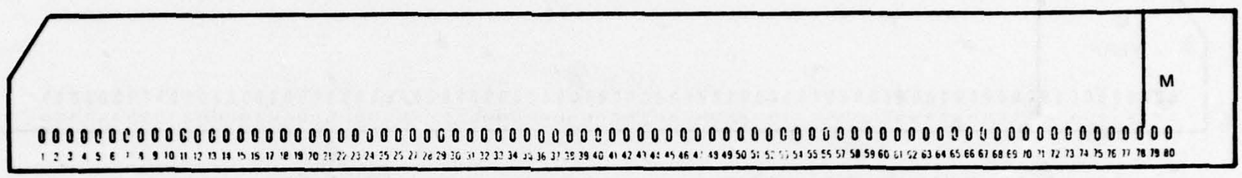
Name	Type	Column(s)	Description
IPERF	INT	1-10	Flight Condition 1. Takeoff 2. Climb 3. Cruise 4. Descent 5. Thrust Reversal
TT4	F.P.	11-20	Compressor Exit Temperature (°F or °R)
TT5	F.P.	21-30	Turbine Inlet Temperature (°F or °R)
FLTIME	F.P.	31-40	Time spent at flight condition (min.)

Card Type: 15 (Required)

Title: Finalizing Card

General Instruction:

If M = 0 on this card, this card would then be the last card. If M = –1 then card type 1 must follow this card.



Name	Type	Column(s)	Description
M	INT	79-80	–1 indicates end of the data for the case.

c. **Sample Case (Input and Output)**

Table 2 consists of a listing of the input for a sample test case. The numbers to the right of the input listing on Table 2 indicate the card type corresponding to the preceding input instructions.

The test case predicts combustor creep low cycle fatigue (LCF), and lip buckling life, for two cases.

TABLE 2

Sample Case

```
FILE: W508AF    DATA

         2        1                                                                1
1038      JT9D BRN MAT'L PACKAGE CRP-LCF,LOUVER BUCKLING RM 11/4/76  (BASE)         2
 8 511 6 92.35      .01       .03        .1        .5       1.                      3
1000.      .745   E 0.495   E 0.396   E-2.246   E 8.76   E-6.118   E 5.102   E 6
-.35229E 1.00     E 0
1400.      .805   E 0.535   E 0.291   E-2.22    E 8.14   E-5.1045  E 5.9     E 5
-.23979E 1.00     E 0
1500.      .720   E 0.485   E 0.265   E-2.21    E 8.157  E-5.94    E 4.82    E 5
-.20458E 1.125    E 0
1600.      .595   E 0.395   E 0.238   E-2.198   E 8.19   E-5.775   E 4.688   E 5
-.16990E 1.23     E 0
1700.      .480   E 0.315   E 0.21    E-2.184   E 8.277  E-5.56    E 4.51    E 5   4
-.13768E 1.318    E 0
1800.      .380   E 0.250   E 0.18    E-2.165   E 8.502  E-5.37    E 4.344   E 5
-.10783E 1.38     E 0
1900.      .31    E 0.200   E 0.149   E-2.136   E 8.770  E-5.213   E 4.213   E 5
-.82390E 0.428    E 0
2000.      .255   E 0.170   E 0.117   E-2.77    E 7.1063 E-4.99    E 3.1     E 5
-.63830E 0.47     E 0
1000.      .179   E-8.185   E-8.198   E-8.222   E-8.237  E-8
1500.      .275   E-5.345   E-5.49    E-5.87    E-5.113  E-4
1600.      .58    E-5.83    E-5.135   E-4.28    E-4.395  E-4                          5
1700.      .98    E-5.166   E-4.28    E-4.56    E-4.97   E-4
1800.      .15    E-4.265   E-4.53    E-4.145   E-3.227  E-3
0.      E 0.2     E-3.4     E-3.6     E-3.8     E-3.1    E-2.15    E-2.2     E-2
.3      E-2.4     E-2.6     E-2.0     E 0.8     E-2.12   E-1.152   E-1.178   E-1    6
.2      E-1.243   E-1.278   E-1.332   E-1.378   E-1.462  E-1
.14     E 4.15    E 4.16    E 4.17    E 4.18    E 4.19   E 4.0     E 0.1     E-2
.2      E-2.3     E-2.4     E-2.5     E-2.1     E-1.15   E-1.2     E-1.0     E 0
.67     E-3.11    E-2.145   E-2.175   E-2.205   E-2.338  E-2.462   E-2.578   E-2
.0      E-0.63    E-3.105   E-2.14    E-2.17    E-2.2    E-2.333   E-2.452   E-2
.565    E-20.     E 0.55    E-3.98    E-3.134   E-2.163  E-2.191   E-2.320   E-2    7
.438    E-2.552   E-2.0     E 0.54    E-3.93    E-3.126  E-2.152   E-2.179   E-2
.302    E-2.412   E-2.517   E-2.0     E 0.4     E-3.82   E-3.113   E-2.14    E-2
.165    E-2.28    E-2.385   E-2.485   E-2.0     E 0.38   E-3.72    E-3.1     E-2
.126    E-2.15    E-2.257   E-2.354   E-2.447   E-2
D7A LKAVGMISSION 10/11/76                                                 1   2   8
  4.0        10.0      1.0                                                        9
10381     HAST-X BRN CRACKING MODEL RM 10/76                                      10
```


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TABLE 2 (Cont'd)

```
 111                                                                          11
1028.     2700.                                                               12
15.     .4     .237     .11     2.     .6    .4 1870. 486. 1295.              13
10382      HAST-X BRN BUCKLING MODEL RM 8/3/76                                10
 111                                                                          11
1028.     2700.                                                               12
15.     .4     .237     .11     3.     .6    .4 1870. 486. 1295.              13
         1    1480.     3024.     2.
         2    1354.     2782.      18.
         3    1260.      2660.    30.
         3    1260.      2660.    30.
         3    1260.      2660.    30.
         3    1260.      2660.    30.                                          14
         3    1260.      2660.    30.
         3    1260.      2660.    30.
         3    1260.      2660.    12.



FILE: W508AF     DATA     A


         4    1150.     2500.     18.0
         5    1356.     2735.     .25                     14
                                                    -1    15
D/A LKAVGMISSION 10/11/76                       1    0     8
  4.0          10.0         1.0                            9
         1    1410.     2960.     2.
         2    1335.     2680.      18.
         3    1160.      2360.    120.                    14
         4   1110.      2260.     18.
         5   1360.      2660.     .25
                                                    -1    15
```

2. Program Output

This section notes the program output listing (Table 3) corresponding to the sample case in Table 2 above. The output has been labeled along the left margin with letters which correspond to the section in the description below:

Section	Description
A	Burner materials properties
B	*Title and flight description*
C1	Reference condition 1, cracking model
C2	Reference condition 2, buckling model
D	Flight condition - time - temperature relationship
E	Description of part life at the end of each increment of the flight profile. Note that the creep and fatigue fractions are all cumulative and are shown for each reference conditions.
E1	This portion of section E is only printed when KPO = 1, and represents the long form print out. Intermediate calculated quantities are printed.
F	Printout of mission life and breakdown of damage by flight portion.
G	Weighted average of the damage and damage breakdown for all the missions run.

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TABLE 3

PROGRAM OUTPUT LISTING

MATN= 0 IBRN= 1

---BURNER MATERIAL PROPERTIES--- 1038 JT9D BRN MAT'L PACKAGE CRP-LCF,LOUVER BUCKLING RM 11/4/76 (BASE)

ETR	WB
0.0	0.0
0.2000E-03	0.8000E-02
0.4000E-03	0.1200E-01
0.6000E-03	0.1520E-01
0.8000E-03	0.1780E-01
0.1000E-02	0.2000E-01
0.1500E-02	0.2430E-01
0.2000E-02	0.2780E-01
0.3000E-02	0.3320E-01
0.4000E-02	0.3780E-01
0.6000E-02	0.4620E-01

CRITICAL PLASTIC STRAIN

TM--KB	0.0	0.00100	0.00200	0.00300	0.00400	0.00500	0.01000	0.01500	0.02000
1400.000	0.0	0.6700E-03	0.1100E-02	0.1450E-02	0.1750E-02	0.2050E-02	0.3380E-02	0.4620E-02	0.5780E-02
1500.000	0.0	0.6300E-03	0.1050E-02	0.1400E-02	0.1700E-02	0.2000E-02	0.3330E-02	0.4520E-02	0.5650E-02
1600.000	0.0	0.5500E-03	0.9800E-03	0.1340E-02	0.1630E-02	0.1910E-02	0.3200E-02	0.4380E-02	0.5520E-02
1700.000	0.0	0.5400E-03	0.9300E-03	0.1260E-02	0.1520E-02	0.1790E-02	0.3020E-02	0.4120E-02	0.5170E-02
1800.000	0.0	0.4000E-03	0.8200E-03	0.1130E-02	0.1400E-02	0.1650E-02	0.2800E-02	0.3850E-02	0.4850E-02
1900.000	0.0	0.3800E-03	0.7200E-03	0.1000E-02	0.1260E-02	0.1500E-02	0.2570E-02	0.3540E-02	0.4470E-02

TMETAL	DP(SMOOTH)	DP(WELDED)	DELTAEE	E	K1	M	B	BETA	DELTAM
1000.000	0.7450E+00	0.4950E+00	0.3960E-02	0.2460E+08	0.7600E-06	0.1180E+05	0.1020E+06	-0.3523E+01	0.0
1400.000	0.8050E+00	0.5350E+00	0.2910E-02	0.2200E+08	0.1400E-05	0.1045E+05	0.9000E+05	-0.2398E+01	0.0
1500.000	0.7200E+00	0.4850E+00	0.2650E-02	0.2100E+08	0.1570E-05	0.9400E+04	0.8200E+05	-0.2046E+01	0.1250E+00
1600.000	0.5950E+00	0.3950E+00	0.2380E-02	0.1980E+08	0.1900E-05	0.7750E+04	0.6880E+05	-0.1699E+01	0.2300E+00
1700.000	0.4800E+00	0.3150E+00	0.2100E-02	0.1840E+08	0.2770E-05	0.5600E+04	0.5100E+05	-0.1377E+01	0.3180E+00
1800.000	0.3800E+00	0.2500E+00	0.1800E-02	0.1650E+08	0.5020E-05	0.3700E+04	0.3440E+05	-0.1078E+01	0.3800E+00
1900.000	0.3100E+00	0.2000E+00	0.1490E-02	0.1360E+08	0.7700E-05	0.2130E+04	0.2130E+05	-0.8239E+00	0.4280E+00
2000.000	0.2550E+00	0.1700E+00	0.1170E-02	0.7700E+07	0.1063E-04	0.9900E+03	0.1000E+05	-0.6383E+00	0.4700E+00

TMETAL	BT T1= 0.010	T2= 0.030	T3= 0.100	T4= 0.500	T5= 1.000
1000.000	0.1790E-08	0.1850E-08	0.1980E-08	0.2220E-08	0.2370E-08
1500.000	0.2750E-05	0.3450E-05	0.4900E-05	0.8700E-05	0.1130E-04
1600.000	0.5800E-05	0.8300E-05	0.1350E-04	0.2800E-04	0.3950E-04
1700.000	0.9800E-05	0.1660E-04	0.2800E-04	0.5600E-04	0.9700E-04
1800.000	0.1500E-04	0.2650E-04	0.5300E-04	0.1450E-03	0.2270E-03

A

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TABLE 3 (Cont'd)

B

```
W50807 MISSION ANALYSIS-- 6/14/77 VERSION

D7A LKAVGMISSION 10/11/76

CASE INFORMATION
KPO= 1        KREF= 2

BLOCK TIME= 4.000 HRS          TAXI TIME= 10.0 MIN           FLIGHT FREQUENCY=    1.00
```

C1

```
************************************************************************************************
REFERENCE CONDITION NC.  1    1038   HAST-X BRN CRACKING MODEL RM 10/76

          BURNER CRACKING MODEL

METAL TEMPERATURE CALCULATED BY TM=TMR+A*(T4-T4R)+B*(T5-T5R)

     REFERENCE POINT NC.  1
          RADIUS=  15.000 IN.        STRESS TYPE IS HOOP-OUTER LINER
          A CONSTANT=   0.600        B CONSTANT=   0.400
          TMETAL=  1870.000
          LOUVER LIP LENGTH =  0.4000
          L**2/RH=  0.2370
          NON-DEFLECTED LOUVER GAP--W=0.1100
          BURNER KB=0.011470         REFERENCE DETR=0.003062
          FLIGHT IDLE--T4=  486.00  T5= 1295.00  DETR=0.1776E-02
```

C2

```
************************************************************************************************
REFERENCE CONDITION NC.  2    1038   HAST-X BRN BUCKLING MODEL RM 8/3/76

          LOUVER BUCKLING MODEL

METAL TEMPERATURE CALCULATED BY TM=TMR+A*(T4-T4R)+B*(T5-T5R)

     REFERENCE POINT NO.  1
          RADIUS=  15.000 IN.        STRESS TYPE IS HOOP-INNER LINER
          A CONSTANT=   0.600        B CONSTANT=   0.400
          TMETAL=  1870.000
          LOUVER LIP LENGTH =  0.4C00
          L**2/RH=  0.2370
          NON-DEFLECTED LOUVER GAP--W=0.1100
          BURNER KB=0.011470         REFERENCE DETR=0.003062
          FLIGHT IDLE--T4=  486.00  T5= 1295.00  DETR=0.1776E-02
```

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TABLE 3 (Cont'd)

```
        --- INPUT FLIGHT CONDITIONS ---

   FLIGHT COND   TT4      TT5    FLIGHT TIME

        1       1480.    3024.      2.
        2       1354.    2782.     18.
        3       1260.    2660.     30.
        3       1260.    2660.     30.
D       3       1260.    2660.     30.
        3       1260.    2660.     30.
        3       1260.    2660.     30.
        3       1260.    2660.     30.
        3       1260.    2660.     12.
        4       1150.    2500.     18.
        5       1356.    2735.      0.

******************************************************************************************

    *****  LIFE CALCULATIONS  *****


   FLIGHT COND   TT4      TT5    FLIGHT TIME

        1       1480.    3024.      2.
E  E1 DETR=0.3873E-02  TM=0.1811E+04  DTM=0.7708E+03  TDAMCR=0.2092E-03  TDAMFA=0.2896E-03
      TM=0.1811E+04  TK=0.1040E+04  TC=0.1754E+04  CRMAX=0.6874E+00  WBMAX=0.2959E-01  ECE=0.2161E-02  DT=0.1250E-01

   REF COND  REF PT.  CREEP FRAC  FATIGUE FRAC
      1         1     0.2092E-03  0.2896E-03
      2         1     0.1250E-01


   FLIGHT COND   TT4      TT5    FLIGHT TIME

        2       1354.    2782.     18.
E  E1 DETR=0.3873E-02  TM=0.1638E+04  DTM=0.7244E+03  TDAMCR=0.2505E-03  TDAMFA=0.2896E-03
      TM=0.1638E+04  TK=0.9140E+03  TC=0.1733E+04  CRMAX=0.6874E+00  WBMAX=0.2959E-01  ECE=0.2477E-02  DT=0.1923E-01

   REF COND  REF PT.  CREEP FRAC  FATIGUE FRAC
      1         1     0.2505E-03  0.2896E-03
      2         1     0.1923E-01
```

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TABLE 3 (Cont'd)

```
FLIGHT COND    TT4         TT5     FLIGHT TIME
         3     1260.       2660.        30.
E1 {DETR=0.3873E-02   TM=0.1533E+04   DTM=0.7132E+03   TDAMCR=0.2607E-03   TDAMFA=0.2896E-03
   {TM=0.1533E+04   TK=0.8200E+03   TC=0.1687E+04   CRMAX=0.6874E+00   WBMAX=0.2959E-01   ECE=0.2622E-02   DT=0.2149E-01

REF COND   REF PT.   CREEP FRAC   FATIGUE FRAC
    1         1      0.2607E-03   0.2896E-03
    2         1      0.2149E-01

FLIGHT COND    TT4         TT5     FLIGHT TIME
         3     1260.       2660.        30.
E1 {DETR=0.3873E-02   TM=0.1533E+04   DTM=0.7132E+03   TDAMCR=0.2646E-03   TDAMFA=0.2896E-03
   {TM=0.1533E+04   TK=0.8200E+03   TC=0.1687E+04   CRMAX=0.6874E+00   WBMAX=0.2959E-01   ECE=0.2622E-02   DT=0.2359E-01

REF COND   REF PT.   CREEP FRAC   FATIGUE FRAC
    1         1      0.2646E-03   0.2896E-03
    2         1      0.2359E-01

FLIGHT COND    TT4         TT5     FLIGHT TIME
         3     1260.       2660.        30.
E1 {DETR=0.3873E-02'  TM=0.1533E+04   DTM=0.7132E+03   TDAMCR=0.2668E-03   TDAMFA=0.2896E-03
   {TM=0.1533E+04   TK=0.8200E+03   TC=0.1687E+04   CRMAX=0.6874E+00   WBMAX=0.2959E-01   ECE=0.2622E-02   DT=0.2556E-01

REF CCND   REF PT.   CREEP FRAC   FATIGUE FRAC
    1         1      0.2668E-03   0.2896E-03
    2         1      0.2556E-01

FLIGHT COND    TT4         TT5     FLIGHT TIME
         3     1260.       2660.        30.
E1 {DETR=0.3873E-02   TM=0.1533E+04   DTM=0.7132E+03   TDAMCR=0.2683E-03   TDAMFA=0.2896E-03
   {TM=0.1533E+04   TK=0.8200E+03   TC=0.1687E+04   CRMAX=0.6874E+00   WBMAX=0.2959E-01   ECE=0.2622E-02   DT=0.2742E-01

REF COND   REF PT.   CREEP FRAC   FATIGUE FRAC
    1         1      0.2683E-03   0.2896E-03
    2         1      0.2742E-01

FLIGHT COND    TT4         TT5     FLIGHT TIME
         3     1260.       2660.        30.
E1 {DETR=0.3873E-02   TM=0.1533E+04   DTM=0.7132E+03   TDAMCR=0.2694E-03   TDAMFA=0.2896E-03
   {TM=0.1533E+04   TK=0.8200E+03   TC=0.1687E+04   CRMAX=0.6874E+00   WBMAX=0.2959E-01   ECE=0.2622E-02   DT=0.2919E-01

REF CCND   REF PT.   CREEP FRAC   FATIGUE FRAC
    1         1      0.2694E-03   0.2896E-03
    2         1      0.2919E-01
```

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TABLE 3 (Cont'd)

```
     FLIGHT COND    TT4 .       TT5     FLIGHT TIME

            3      1260.       2660.         30.
E  E1 DETR=0.3873E-02  TM=0.1533E+04  DTM=0.7132E+03  TDAMCR=0.2702E-03  TDAMFA=0.2896E-03
      TM=0.1533E+04  TK=0.8200E+03  TC=0.1687E+04  CRMAX=0.6874E+00  WBMAX=0.2959E-01  ECE=0.2622E-02  DT=0.3089E-01

     REF COND   REF PT.   CREEP FRAC  FATIGUE FRAC
        1          1     0.2702E-03  0.2896E-03
        2          1     0.3089E-01

     FLIGHT COND    TT4         TT5     FLIGHT TIME

            3      1260.       2660.         12.
E  E1 DETR=0.3873E-02  TM=0.1533E+04  DTM=0.7132E+03  TDAMCR=0.2704E-03  TDAMFA=0.2896E-03
      TM=0.1533E+04  TK=0.8200E+03  TC=0.1687E+04  CRMAX=0.6874E+00  WBMAX=0.2959E-01  ECE=0.2622E-02  DT=0.3155E-01

     REF COND   REF PT.   CREEP FRAC  FATIGUE FRAC
        1          1     0.2704E-03  0.2896E-03
        2          1     0.3155E-01

     FLIGHT COND    TT4         TT5     FLIGHT TIME

            4      1150.       2500.         18.
E  E1 DETR=0.3873E-02  TM=0.1403E+04  DTM=0.6932E+03  TDAMCR=0.2710E-03  TDAMFA=0.2896E-03
      TM=0.1403E+04  TK=0.7100E+03  TC=0.1601E+04  CRMAX=0.6874E+00  WBMAX=0.2959E-01  ECE=0.2697E-02  DT=0.3171E-01

     REF COND   REF PT.   CREEP FRAC  FATIGUE FRAC
        1          1     0.2710E-03  0.2896E-03
        2          1     0.3171E-01

     FLIGHT COND    TT4         TT5     FLIGHT TIME

            5      1356.       2735.          0.
E  E1 DETR=0.3542E-02  TM=0.1621E+04  DTM=0.7048E+03  TDAMCR=0.3461E-03  TDAMFA=0.2896E-03
      TM=0.1621E+04  TK=0.9160E+03  TC=0.1745E+04  CRMAX=0.6874E+00  WBMAX=0.2959E-01  ECE=0.2507E-02  DT=0.3176E-01

     REF COND   REF PT.   CREEP FRAC  FATIGUE FRAC
        1          1     0.3461E-03  0.2896E-03
        2          1     0.3176E-01
```

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TABLE 3 (Cont'd)

```
******************************************************************************************
REFERENCE CONDITION NO.  1     1038    HAST-X BRN CRACKING MCDEL RM 10/76

      REFERENCE POINT NO.  1
           CYCLIC LIFE=              1573.10
           LIFE BASED ON BLOCK TIME=             6292.41
           LIFE BASED ON FLIGHT TIME=             6030.23

F   PERCENT CREEP DAMAGE BREAKDOWN

         TAKE OFF  78.46
         CLIMB      6.50
         CRUISE     3.14
         DESCENT    0.09
         FN REV    11.81
******************************************************************************************
REFERENCE CONDITION NO.  2     1038    HAST-X BRN BUCKLING MODEL RM 8/3/76

      REFERENCE POINT NO.  1
           CYCLIC LIFE=               938.54
           LIFE BASED ON BLOCK TIME=             3754.16
           LIFE BASED ON FLIGHT TIME=            3597.74

F   PERCENT CREEP DAMAGE BREAKDOWN

         TAKE OFF  39.36
         CLIMB     21.20
         CRUISE    38.80
         DESCENT    0.50
         FN REV     0.14

         W50807 MISSION ANALYSIS-- 6/14/77 VERSION

         D7A LKAVGMISSION 10/11/76

B        CASE INFORMATION
         KPO= 1          KREF= 0

         BLOCK TIME= 4.000 HRS          TAXI TIME= 10.0 MIN          FLIGHT FREQUENCY=    1.00

      --- INPUT FLIGHT CONDITIONS ---

    FLIGHT COND   TT4       TT5    FLIGHT TIME

D        1       1410.     2960.        2.
         2       1335.     2680.       18.
         3       1160.     2360.      120.
         4       1110.     2260.       18.
         5       1360.     2660.        0.
```

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TABLE 3 (Cont'd)

```
     *****  LIFE CALCULATIONS    *****

      FLIGHT COND   TT4        TT5    FLIGHT TIME

              1      1410.      2960.        2.
   E1 DETR=0.3885E-02  TM=0.1743E+04  DTM=0.7732E+03  TDAMCR=0.1887E-03  TDAMFA=0.1894E-03
E     TM=0.1743E+04  TK=0.9700E+03  TC=0.1725E+04  CRMAX=0.6205E+00  WBMAX=0.2963E-01  ECE=0.2285E-02  DT=0.7941E-02

      REF COND  REF PT.  CREEP FRAC  FATIGUE FRAC
         1        1    0.1887E-03  0.1894E-03
         2        1    0.7941E-02

      FLIGHT COND   TT4        TT5    FLIGHT TIME

              2      1335.      2680.       18.
   E1 DETR=0.3885E-02  TM=0.1586E+04  DTM=0.6912E+03  TDAMCR=0.2298E-03  TDAMFA=0.1894E-03
E     TM=0.1586E+04  TK=0.8950E+03  TC=0.1741E+04  CRMAX=0.6205E+00  WBMAX=0.2963E-01  ECE=0.2559E-02  DT=0.1261E-01

      REF COND  REF PT.  CREEP FRAC  FATIGUE FRAC
         1        1    0.2298E-03  0.1894E-03
         2        1    0.1261E-01

      FLIGHT COND   TT4        TT5    FLIGHT TIME

              3      1160.      2360.      120.
   E1 DETR=0.3885E-02  TM=0.1353E+04  DTM=0.6332E+03  TDAMCR=0.2827E-03  TDAMFA=0.1894E-03
E     TM=0.1353E+04  TK=0.7200E+03  TC=0.1615E+04  CRMAX=0.6205E+00  WBMAX=0.2963E-01  ECE=0.2708E-02  DT=0.1261E-01

      REF COND  REF PT.  CREEP FRAC  FATIGUE FRAC
         1        1    0.2827E-03  0.1894E-03
         2        1    0.1261E-01

      FLIGHT COND   TT4        TT5    FLIGHT TIME

              4      1110.      2260.       18.
   E1 DETR=0.3885E-02  TM=0.1283E+04  DTM=0.6132E+03  TDAMCR=0.2850E-03  TDAMFA=0.1894E-03
E     TM=0.1283E+04  TK=0.6700E+03  TC=0.1573E+04  CRMAX=0.6205E+00  WBMAX=0.2963E-01  ECE=0.2733E-02  DT=0.1261E-01

      REF COND  REF PT.  CREEP FRAC  FATIGUE FRAC
         1        1    0.2850E-03  0.1894E-03
         2        1    0.1261E-01

      FLIGHT COND   TT4        TT5    FLIGHT TIME

              5      1360.      2660.        0.
   E1 DETR=0.3383E-02  TM=0.1593E+04  DTM=0.6732E+03  TDAMCR=0.5186E-03  TDAMFA=0.2258E-03
E     TM=0.1593E+04  TK=0.9200E+03  TC=0.1762E+04  CRMAX=0.6205E+00  WBMAX=0.2963E-01  ECE=0.2548E-02  DT=0.1267E-01

      REF COND  REF PT.  CREEP FRAC  FATIGUE FRAC
         1        1    0.5186E-03  0.2258E-03
         2        1    0.1267E-01
```

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TABLE 3 (Cont'd)

```
******************************************************************************
  REFERENCE CONDITION NC.  1    1038   HAST-X BRN CRACKING MODEL RM 10/76

       REFERENCE POINT NC.  1
            CYCLIC LIFE=          1343.43
            LIFE BASED CN BLOCK TIME=          5373.71
            LIFE BASED ON FLIGHT TIME=          5149.81


  PERCENT CREEP DAMAGE BREAKDOWN

         TAKE OFF  50.79
         CLIMB      5.52
         CRUISE     7.11
         DESCENT    0.30
         FN REV    36.28
******************************************************************************
  REFERENCE CONDITION NC.  2    1038   HAST-X BRN BUCKLING MODEL RM 8/3/76

       REFERENCE POINT NC.  1
            CYCLIC LIFE=          5524.48
            LIFE BASED CN BLOCK TIME=         22097.91
            LIFE BASED CN FLIGHT TIME=         21177.17


  PERCENT CREEP DAMAGE BREAKDOWN

         TAKE OFF  62.67
         CLIMB     36.84
         CRUISE     0.0
         DESCENT    0.0
         FN REV     0.48
```

F

F

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TABLE 3 (Cont'd)

G

```
*****    REFERENCE CONDITION SUMMARY    *****

          AVERAGE FLIGHT TIME =            3.83
          AVERAGE BLOCK TIME =            4.00
          TOTAL FREQUENCY =            2.00

**********************************************************************
REFERENCE CONDITION NO.  1    1038    HAST-X BRN CRACKING MODEL RM 10/76

     REFERENCE POINT NO.  1
          CYCLIC LIFE=          1449.22
          LIFE BASED ON BLOCK TIME=          5796.89
          LIFE BASED CN FLIGHT TIME=          5313.81


PERCENT CREEP DAMAGE BREAKDOWN

       TAKE OFF  63.54
       CLIMB      5.97
       CRUISE     5.28
       DESCENT    0.21
       FN REV    25.01

**********************************************************************
REFERENCE CONDITION NO.  2    1038    HAST-X BRN BUCKLING MODEL RM 8/3/76

     REFERENCE POINT NO.  1
          CYCLIC LIFE=          1604.50
          LIFE BASED ON BLOCK TIME=          6417.99
          LIFE BASED CN FLIGHT TIME=          5883.15


PERCENT CREEP DAMAGE BREAKDOWN

       TAKE OFF  46.01
       CLIMB     25.66
       CRUISE    27.73
       DESCENT    0.36
       FN REV     0.24
```


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